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GEORGE C. MARSHALL SPACE FLIGHT CENTER

HUNTSVILLE, ALABAMA

A PRELIMINARY INVESTIGATION OF THE MEASURED ATMOSPHERIC EFFECTS UPON SOUND PROPAGATION

by

Richard N. Tedrick
Robert C. Polly

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ABSTRACT

To protect the surrounding communities from the high-intensity noise fields which are produced during the static test firing of large space vehicles, MSFC has investigated the effects of atmospheric changes upon acoustic propagation. Since the net effect of changes in the temperature and wind parameters is to change the velocity of sound distribution with altitude, these changes also result in variations of sound pressure level beyond one kilometer.

The types of possible velocity of sound versus altitude profiles are categorized. The characteristic sound pressure level distribution for each category is then illustrated and discussed. Also discussed are observed seasonal variations in measured sound pressure level under certain meteorological conditions. Measured data are presented showing the effects of molecular absorption upon low frequency acoustic propagation.

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TEST DIVISION

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SUMMARY

To protect the surrounding communities from the high-intensity noise fields which are produced during the static test firing of large space vehicles, MSFC has investigated the effects of atmospheric changes upon acoustic propagation. Since the net effect of changes in the temperature and wind parameters is to change the velocity of sound magnitude with altitude, these changes cause sound ray deflections and thus also result in variations of sound pressure level beyond one kilometer.

The types of possible velocity of sound versus altitude profiles are categorized. The characteristic sound pressure level distribution for each category is then illustrated and discussed. Also discussed are observed seasonal variations in measured sound pressure level under certain meteorological conditions. Measured data are presented showing the effects of molecular absorption upon low frequency acoustic propagation.

INTRODUCTION

Since one of the results of the static tests of large space vehicles is the production of high-intensity sound fields, the George C. Marshall Space Flight Center has had the responsibility of firing under conditions which would provide little or no annoyance to the surrounding civilian communities. The dominant feature has been found to be the meteorological conditions along the path from the source to the receiver, i.e., from the static test stand to some particular housing or business area. (See Ref. 1). To better gain an understanding of how the meteorology affects acoustic propagation and thereby effectively raises or lowers the sound pressure levels at great distances, MSFC's Test Division devised a large electro-pneumatic transducer and exponential horn system which could be utilized in lieu of the static tests themselves for the generation of large amounts of sound energy along a single azimuth. (See Reference 2 for the electrical,mechanical and acoustical characteristics of the horn system). This equipment was used for almost a year (March through October 1962) at MSFC before being sent to the Mississippi Test Facility to make similar on-site measurements there. This report constitutes a preliminary study of the MSFC data.

BACKGROUND

Several authors (Refs. 1, 3, 4, and 5) have shown that acoustic energy propagating away from the earths' surface through the atmosphere can, under specified circumstances, be refracted (bent) back toward the ground. However in the past, this effect has rarely been of practical interest because of the limited signal strengths which it was possible to sustain over appreciable periods. Since the development of the large rocket engine, interest in the effects of refraction has assumed greater importance, especially with regard to the civilian areas surrounding the test sites for such large rocket engines. At Marshall Space Flight Center the acoustical focusing problem is intensified because of the location of the city of Huntsville, Alabama. Normally, the city is downwind from the Saturn Static Test Tower at a distance of ten to fifteen kilometers. During the winter months the westerly-southwesterly wind pattern intensifies and is quite often accompanied by a strong surface inversion. These conditions cause focusing of acoustic energy along the azimuths toward the city. Naturally, such focusing conditions do not occur every day, nor do they necessarily last all day during those days on which they do occur. Nevertheless, examination of past meteorological data shows that such conditions may exist for varying lengths of time during any season or month.

One method of reducing such a problem is the investigation, on a routine day-to-day basis of those areas which are acoustically affected by large-scale space vehicle tests. This, of course, leads into a very exhaustive (and expensive) series of static test firings. However, by substituting another large-scale (but more convenient and inexpensive) noise source, such a program can be instituted. Toward this end, a large exponential horn powered by four electro-pneumatic transducers was devised and installed (See Reference 2 for design and performance characteristics of the horn and transducer system). Data were collected for a period of nearly one year at Marshall Space Flight Center before the horn system was moved to the Mississippi Test Facility. This report is intended as a preliminary study of those data.

Perkins (Reference 3) investigated the effects of changing meteorological conditions in the lower atmosphere upon the focusing and non-focusing of acoustical energies. In this investigation he found it convenient to categorize the types of atmosphere through which the acoustic energy may pass on its way from source to receiver. He stated that the acoustic profile (the velocity of sound versus altitude curve) along the sound path would normally fall into one of five general categories.

In the study of the horn data from MSFC, it has been found convenient to utilize Mr. Perkins' five categories along with a "zero' or no-characteristics profile type. (See Figure 1). This latter category, while rare in nature, is that which is most often assumed in theoretical calculation of the far-field effects of large noise sources. This results generally from the assumption of a single-layered, homogeneous atmosphere. In such an atmosphere, sound would propagate even at long ranges as it does in laboratory experiments subject only to slight corrections for molecular absorption (the so-called) "excess attenuation" . Another way of defining the "zero" conditions would be those conditions under which the rays of sound energy are propagated along straight lines. This definition does not restrict the applicable atmosphere to only one condition, but rather restricts it to any of a family of fortuitous circumstances which have the same net result. Thus, while neither the wind nor the temperature profiles along a given azimuth may be single-valued, their resultant vector sum along that azimuth may be. This effect is of importance, not only because many engineering estimates of far-field sound contours have been predicted upon this condition, but also because the physical effect of atmospheric variations is to either raise or lower the sound pressure level from that which would have occurred under "zero" conditions. Said another way, the "zero" condition is a convenient and natural baseline both for calculation and measurement. In this report, the results of each of the other five profile categories are plotted against the measured sound pressure levels under "zero" baseline conditions.

DISCUSSION

Several times during the measurement period "zero" category conditions occurred out azimuths which were conducive to measurement. The results are shown in Figure 2. They were plotted on a scale somewhat different from the usual presentation for acoustical data insomuch as the ordinate reference value is the "inverse square law". (See Reference 2 for a discussion of the inverse square law's effect upon horn performance). Since these data were based upon the propagation of a shaped random noise (approximately 20 through 2000 cycles per second) propagating through the atmosphere, the excess attenuation coefficient shown should agree fairly well with that for similar rocket engine developed spectra. The 0.8 decibel per kilometer agrees with the value shown in Table I of Reference 6.

The average "zero" condition shown is extended to about sixteen kilometers. However, the portion of the curve beyond 7.8 kilometers is not based upon a large enough statistical sampling to compute a reliable standard deviation, so none is presented. (The standard deviation is defined as the positive square root of the sum of the square of the deviations of the observations from the observed arithmetic mean, divided by one less than the total number of observations. See Chapter 3 of Reference 7).

The "zero" curve in Figure 2 continues smoothly outward until about twelve and one-half kilometers where it rises sharply. This rise is common to all the measurements made under all the various weather conditions, and seems to be the result of the topography out the 45 degree azimuth since the measuring points beyond that range are atop a mountain which is a thousand feet above the plane of the other measurement points. Whether the effect of this mountain is simply that of the added elevation, or is that physically associated with the changes in the prevailing meteorology from plain to mountain is as yet unknown.

The sound pressure level variations versus range which occurred during category "one" conditions are presented in Figure 3. This presentation is also somewhat non-standard in that the zero ordinate is the "zero" condition mentioned above. In other words, the category "1" measurements are plotted using variations from Category "0" as the ordinate. As can be seen, the "one" conditions averaged approximately five decibels below the "zero" conditions, reflecting the effect of refracting the sound away from the earth's surface. The slight rise in sound pressure level beyond nine kilometers may also be due to a topographic effect upon the wind and temperature structures.

Since one of the primary reasons for building and operating the horn system was to estimate the sound pressure levels which might result from the static test firing of the Saturn space vehicle, a shaped random noise was radiated into the atmosphere. The signal attenuated with distance as did also the Saturn noise. Accounting for the differences in spectra and using the attenuation coefficients from Table I of Reference 6, the spread, or difference, between the two sound pressure levels was calculated for the ranges out through sixteen kilometers. The differences were measured during several static tests, comparing the levels from the Saturn with those measured from horn soundings made within fifteen minutes of the static tests. Both the measured and calculated sound pressure level differences between the Saturn and the horn are shown in Figure 4. The two curves are, at all points, within plus or minus three decibels of each other.

One of the characteristics of the period which was statistically sampled was the predominance of category "one" conditions. This could be expected since the sampling was taken during the summer and omitted winter conditions. In fact over two thirds of the profiles were of this type. An examination of the results of all these conditions showed one interesting phenomenon. It appeared that the acoustic levels resulting from the same type of profile varied from month to month even though the horn power was held constant. This seemed to fit a seasonal pattern. These variations are presented in Figure 5 for the five stations at which sufficient data were taken during the entire period. All of these five stations are out a single azimuth (45°).

Any explanation of the above apparent incongruity must lie in the physical quantities which go together to make up the acoustical profile. Since this profile is defined as the vector sum at each altitude of the wind velocity and the velocity of sound due to temperature, it can be seen that when fifty or a hundred such profiles may be similar one to another, any seasonal variations in either wind or temperature characteristics must, of necessity, be off-set by some compensating change in the other. Thus, in the summer when the surface temperatures are relatively much higher, the "one" conditions are usually dominated by the temperature profile; whereas in the winter the wind usually shapes the profile. If, therefore, the localized inhomogeneities (gusts) in the wind and temperature are basically different from one another in size, shape, or intensity, this could cause the spill-out into the category "one's" shadow zone to change with season. Said another way, local complexities may vary the profile from a simple category "one" and cause variations in the shadow zones. No such seasonal variation in sound pressure levels was found during the conditions (categories 2, 3, and 4) in which no shadow zones were formed. Category "five" is the only other condition under which a strong shadow zone was formed, but due to its relative rarity during most of the year in the MSFC - Huntsville area, it was impossible to determine if such a seasonal variation might also exist for it.

In Figure 6 the sound pressure level variations versus range are shown for Category "two" conditions. As in Figure 3, the ordinate reference level is the average "zero" condition from Figure 2.

There seems to be a certain bimodality to Category "two", since there are actually two distinct and separate curves for the sound pressure level distribution under that condition. If one defines the slope (K) of the velocity of sound profile in meters per second per thousand meters, then the values of K = 0.015 become the dividing line. Profiles which have a slope greater than K = 0.015 have a strong concentration along the whole sixteen kilometer long measured range. The maximum rise over the "zero" conditions occurred at nine kilometers and amounted to an average of sixteen decibels. The rises resulting from the profiles which had slopes of less than K = 0.015 had minor maxima at three and thirteen kilometers which accounted for only five and three decibels, respectively.

Category conditions "three" and "four" were relatively rare (less than ten percent) during the test period. They also seemed to result in about the same sound pressure level distributions with range. They were therefore graphed together in Figure 7. Out to three kilometers, the levels are less than those measured under "zero" conditions. Beyond that, the sound pressure levels rise to fourteen decibels above the zero. The average levels then do not appear to drop off again out as far as the measurement program went (sixteen kilometers).

Category "five" results in a shadow zone and then a focal area in range. During the measurement program using the horn system, only those "five" conditions in which part or all of the focal area fell within the measured zone were averaged into the "five" column. The others were then for all purposes category "one" and were averaged with the "ones".

The maximum average value of sound pressure level which was measured for the "five" conditions (Figure 8) was fourteen decibels at twelve kilometers. The shadow zone extended to four and one-half kilometers. It was found that, while the average curves blended shadow zones and focal areas smoothly with range, the individual focal area boundaries might rise much more sharply, sometimes as much as fifteen decibels per kilometer.

EXCESS ATTENUATION

One of the large questions which the advent of large space vehicle testing has raised is that of the propagation of low frequency energy through air. Very few experiments have been carried out in this field below one thousand cycles per second, either in the laboratory or in the field. This has been due, at least in part, to a lack of a high-power, low-frequency source. Within certain frequency limits, the horn system has proven itself capable of such use. Although the system was primarily used to investigate the gross effects of atmospheric changes in such things as velocity of sound profiles, a certain amount of data were taken showing the value of excess attenuation coefficients. The coefficients represent the absorption of sound energy by the molecules of the atmosphere through which the sound passes. (See Reference 8 for a more complete discussion and evaluation of excess attenuation).

In Figure 9, the measured values of the excess attenuation coefficients for the octave bands from fifty through two hundred cycles per second are shown. Also shown are the range of measured values and an estimate of the true excess attenuation in the octave bands from fifty through thirty-two hundred cycles per second. These last two quantities are from Reference 9. The measured values from the horn, though covering only a small portion of the noise spectrum, do appear to verify the Bolt, Beranek and Newman estimate from Reference 9.

CONCLUSIONS

The ten months of acoustic data herein presented have given the first comprehensive look at the effects of changes in the various atmospheric parameters as far as sound pressure levels in the far field are concerned. This is also the first study of the characteristics of acoustic propagation in the MSFC - Huntsville, Alabama, area. However, as the first, it must stand as only tentative. Much more data and evaluation are still required. Since this report is concerned with acoustic propagation out only one azimuth, from only one geographical location, the universal application of these findings must also remain in doubt.

Because of the limited frequency data which were obtained during this study, only limited knowledge was gained in this area. However, a better understanding of low frequency attenuation coefficients is one of the possible rewards of a continued study of this nature.

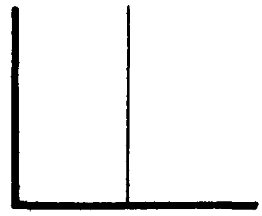
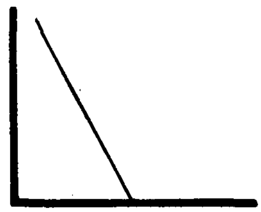
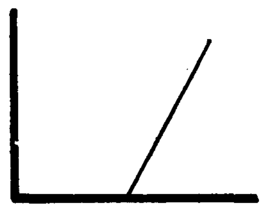
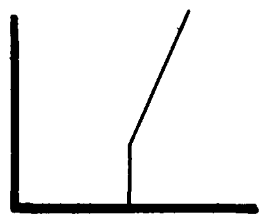
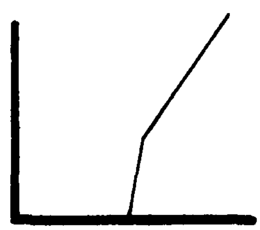
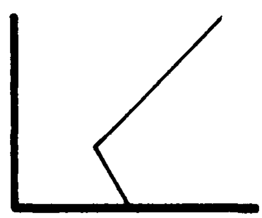
CATEGORY	DESCRIPTION	
0	NO VELOCITY GRADIENT	
1	SINGLE NEGATIVE GRADIENT	
2	SINGLE POSITIVE GRADIENT	
3	ZERO GRADIENT NEAR SURFACE WITH POSITIVE GRADIENT ABOVE	
4	WEAK POSITIVE GRADIENT NEAR SURFACE WITH STRONG POSITIVE GRADIENT ABOVE	
5	NEGATIVE GRADIENT NEAR SURFACE WITH STRONG POSITIVE GRADIENT ABOVE	

FIGURE I. ACOUSTIC VELOCITY PROFILE CATEGORIES

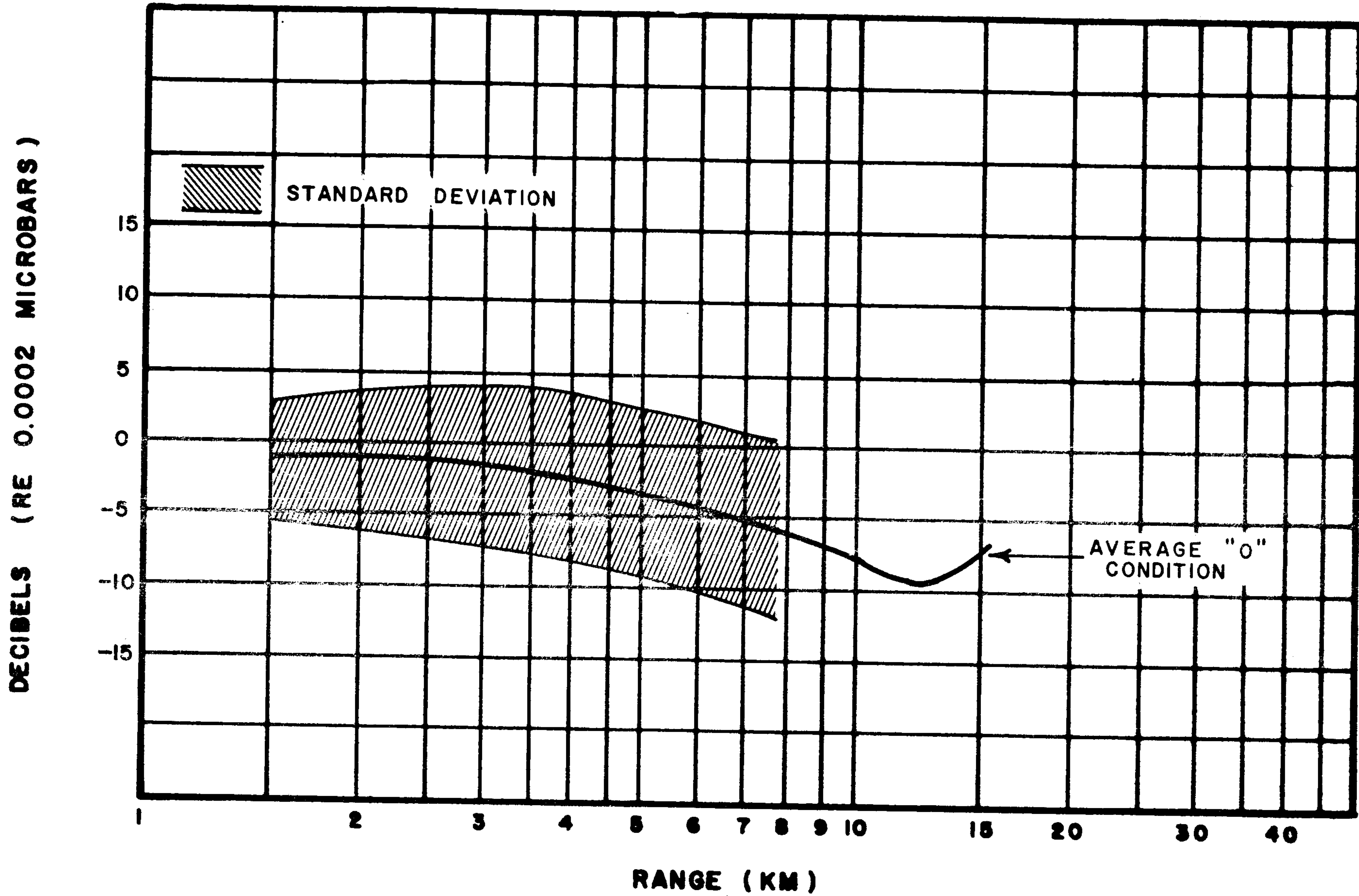


FIGURE 2. SOUND PRESSURE LEVEL VARIATION VERSUS RANGE DURING CATEGORY "O" CONDITIONS (INVERSE SQUARE LAW REFERENCE)

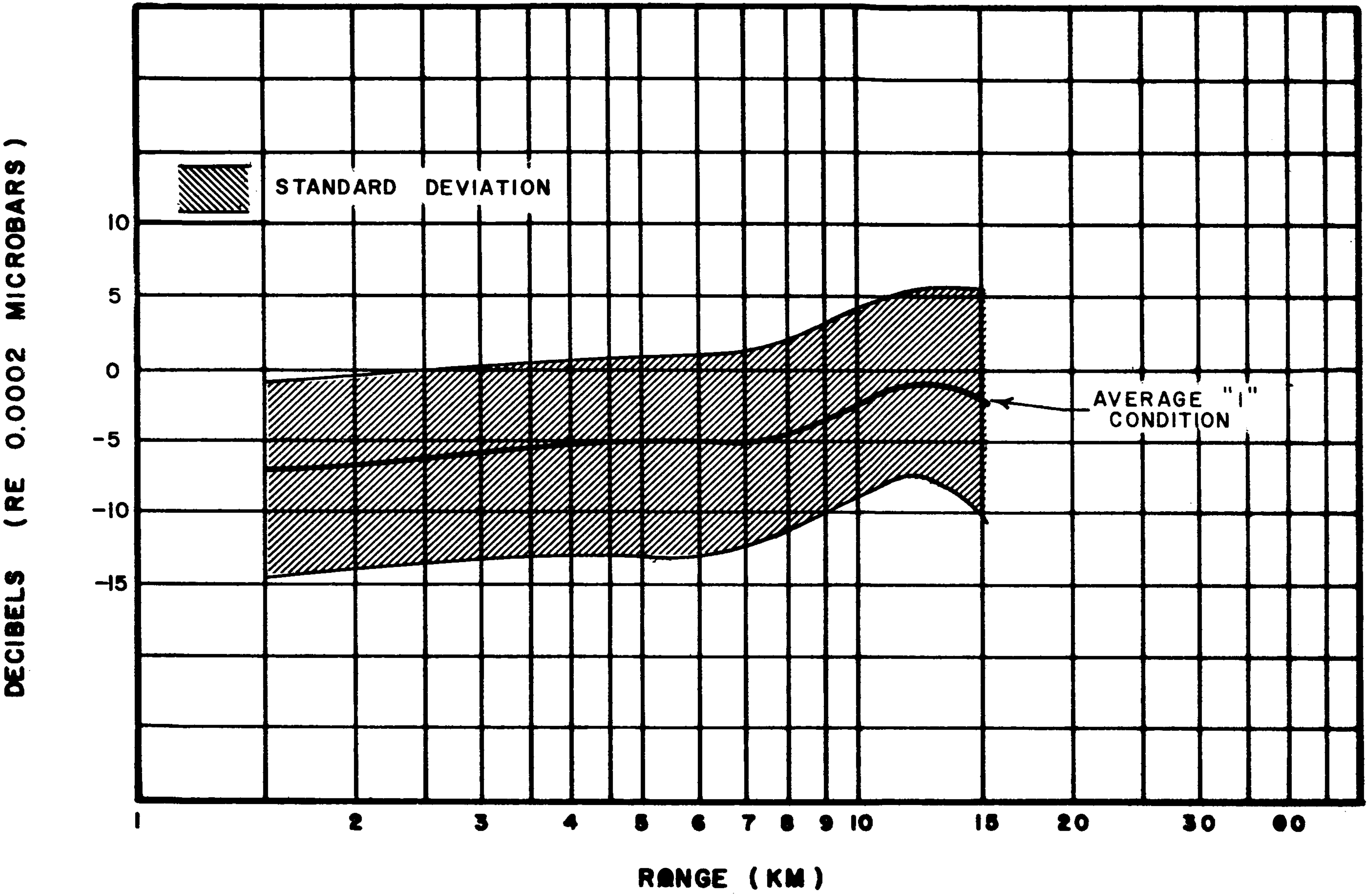


FIGURE 3. SOUND PRESSURE LEVEL VARIATION VERSUS RANGE DURING CATEGORY "I" CONDITIONS (ZERO CONDITION REFERENCE)

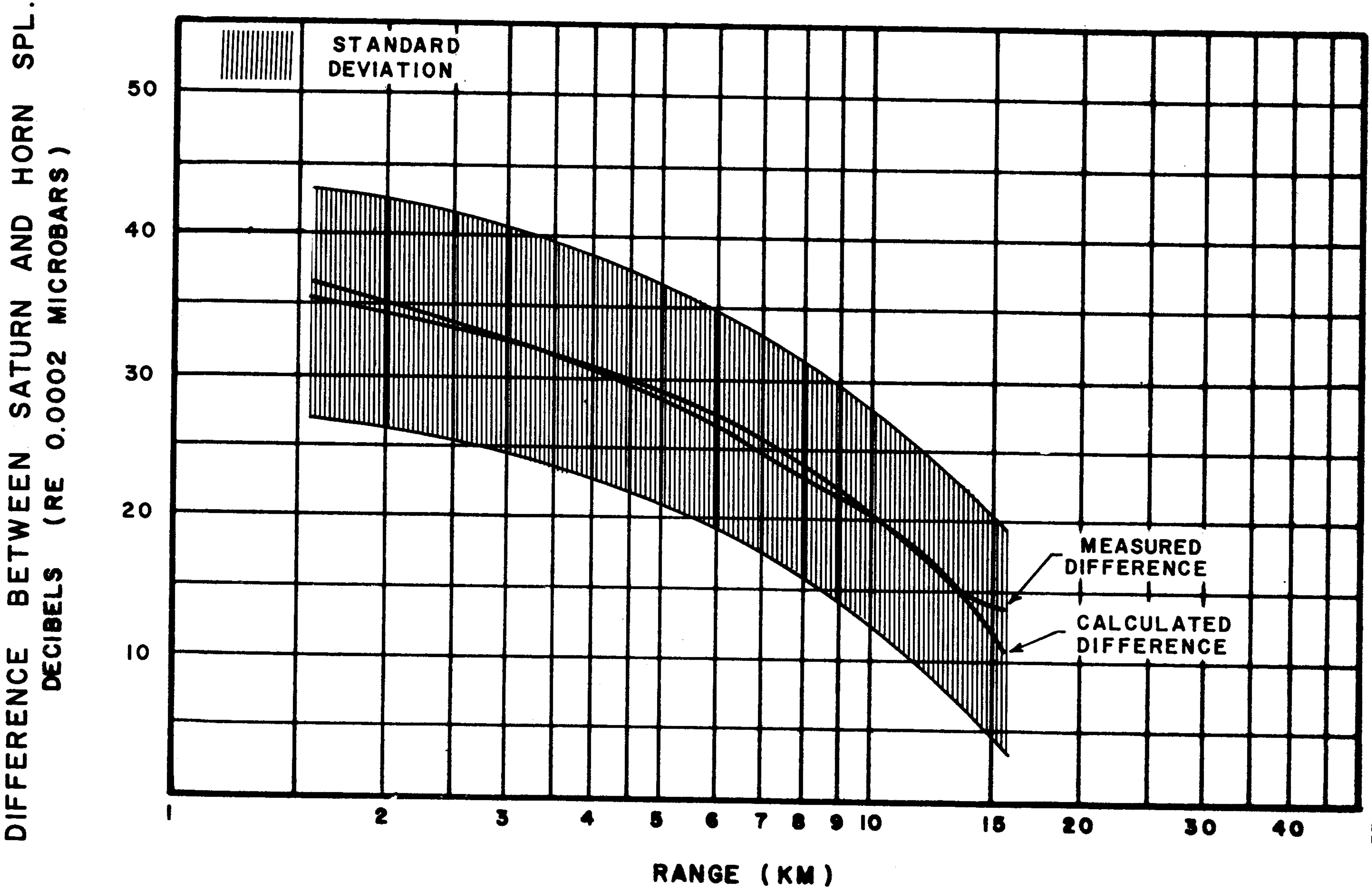


FIGURE 4. CALCULATED AND MEASURED DIFFERENCES BETWEEN HORN AND SATURN ACOUSTIC LEVELS MEASURED DURING TYPE "I" VELOCITY PROFILE CONDITIONS

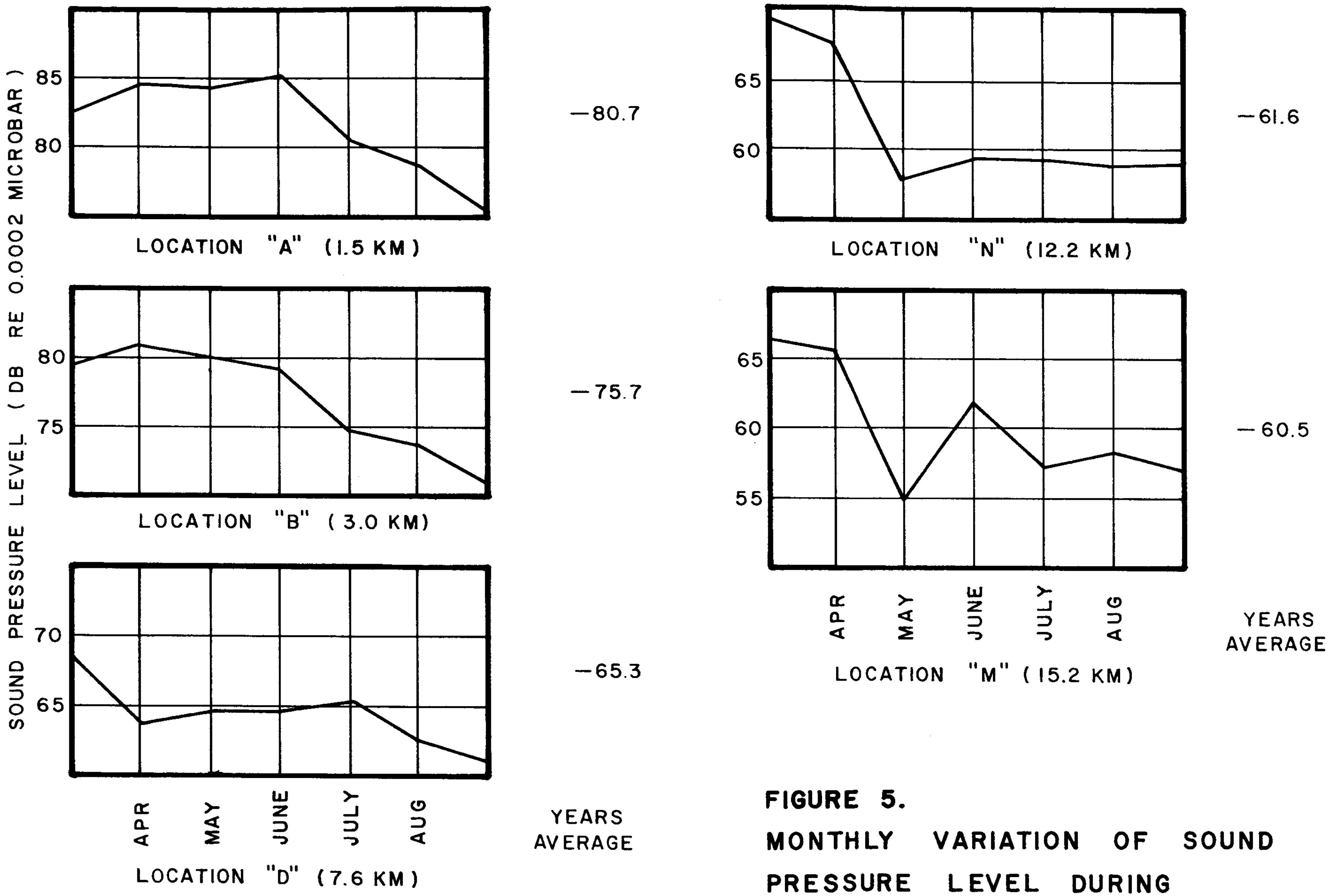


FIGURE 5.
MONTHLY VARIATION OF SOUND PRESSURE LEVEL DURING CATEGORY "I" CONDITIONS

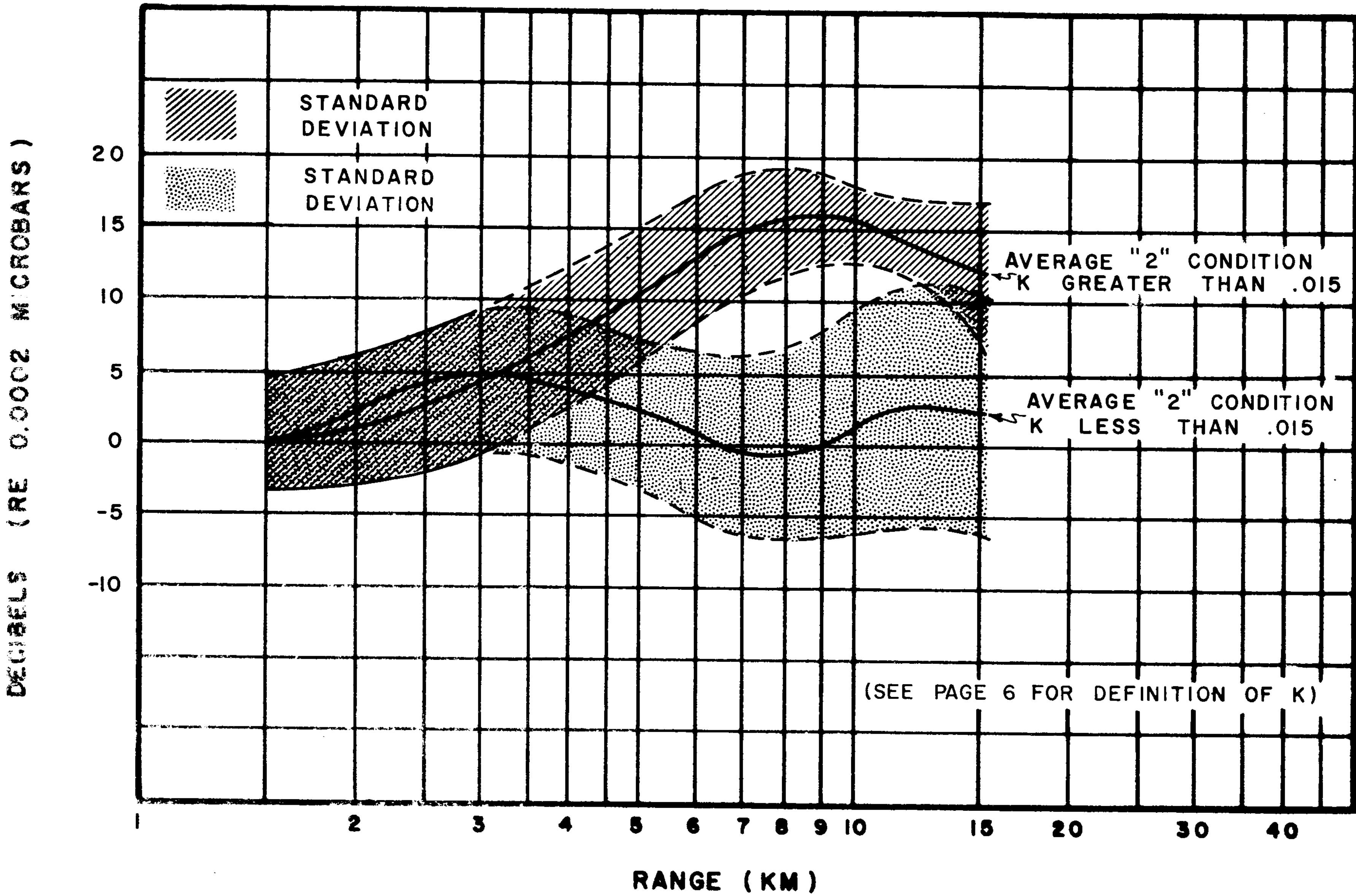


FIGURE 6. SOUND PRESSURE LEVEL VARIATION VERSUS RANGE DURING CATEGORY "2" CONDITIONS (ZERO CONDITION REFERENCE)

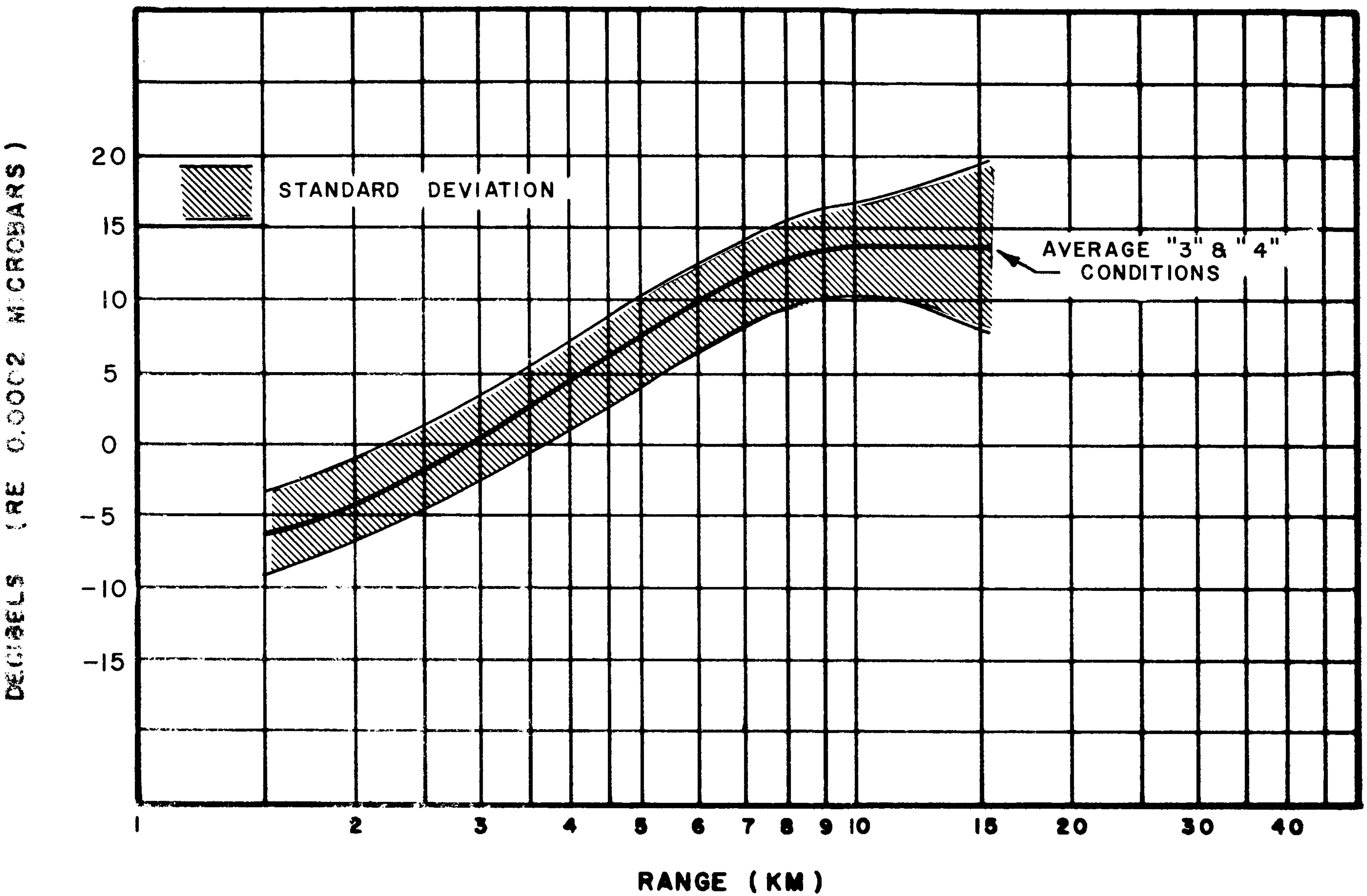


FIGURE 7. SOUND PRESSURE LEVEL VARIATION VERSUS RANGE DURING CATEGORY "3" & "4" CONDITIONS (ZERO CONDITION REFERENCE)

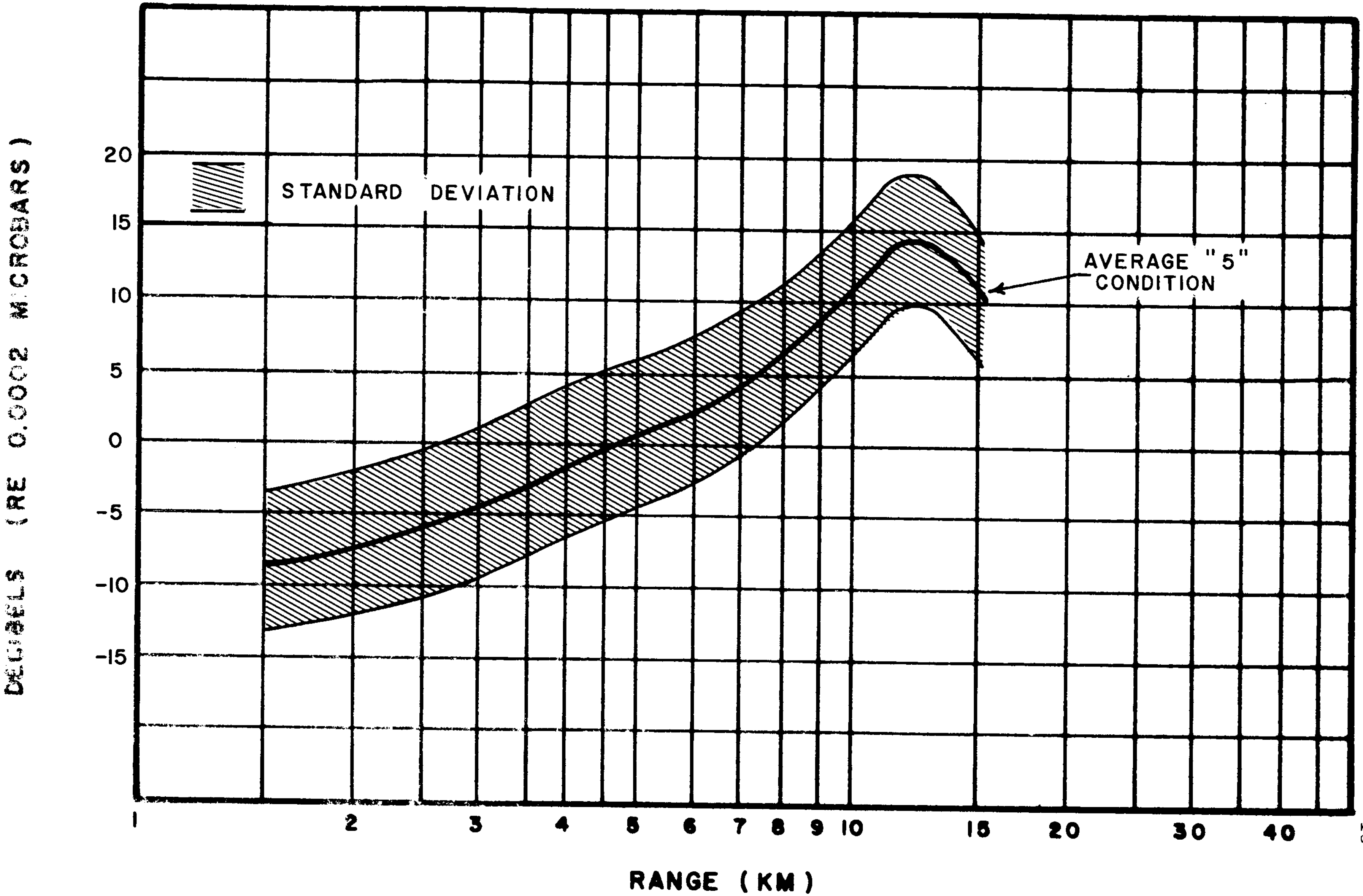


FIGURE 8. SOUND PRESSURE LEVEL VARIATION VERSUS RANGE DURING CATEGORY "5" CONDITIONS (ZERO CONDITION REFERENCE)

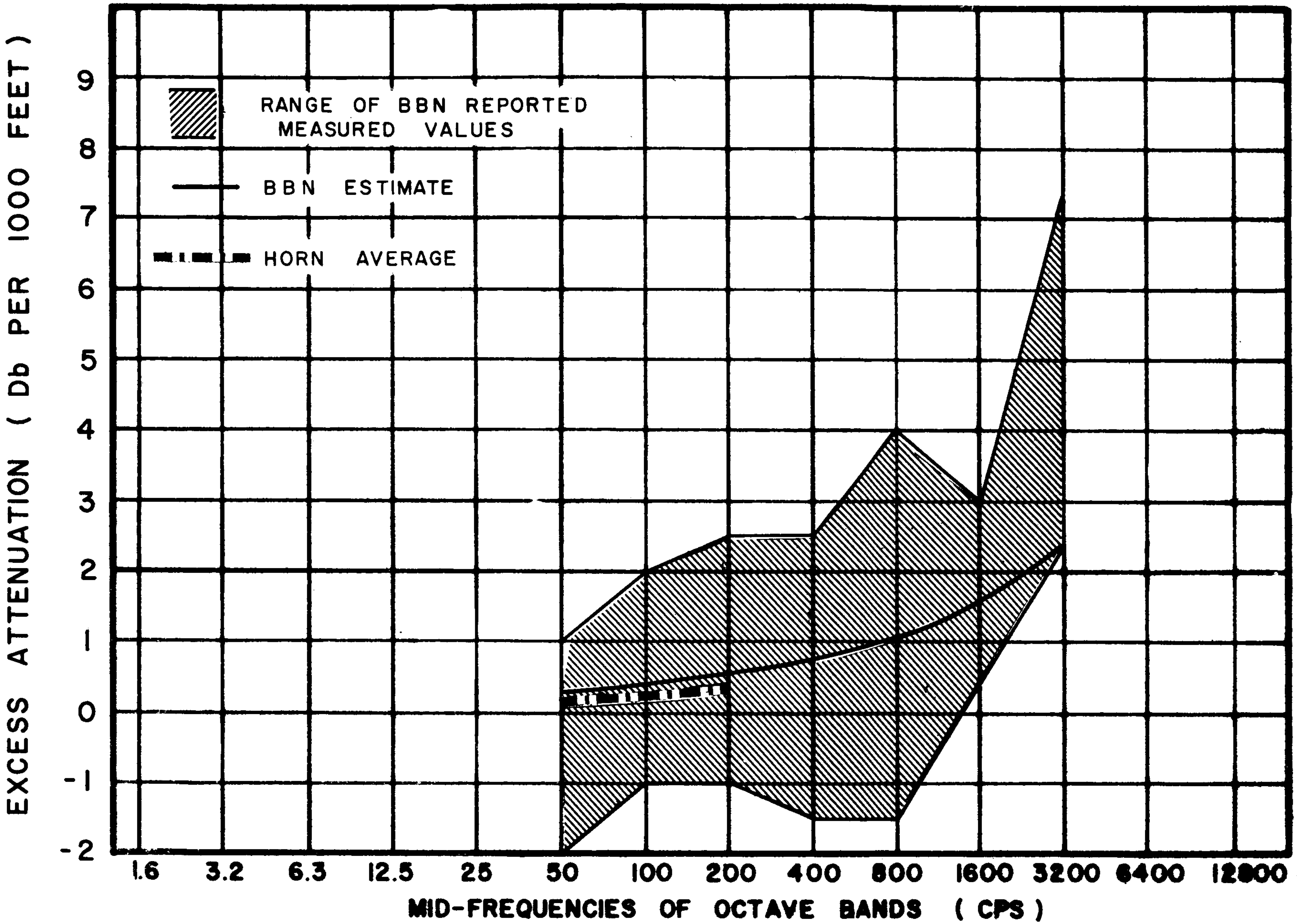


FIGURE 9. MEASURED EXCESS ATTENUATION AS A FUNCTION OF FREQUENCY

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The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officier. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed for technical accuracy.

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